APPENDIX C

Satellite Imagery Interpretation

APPROACH

Interpreting satellite imagery closely parallels making weather forecasts. There are three levels of knowledge needed in order to proceed in an organized and productive manner.

1. Regional climatology
2. Current synoptic pattern
3. Local conditions

Climatology

In both imagery interpretation and knowledgable forecasting for the area, climatology is vital. Familiarity with the typical circulation patterns, extremes, pattern evolutions and models of the dynamic and thermal structures provide the general framework within which the interpretations are made. A series of annotated images or representative case studies is needed to acquire an understanding of the climatology of a region as reflected in satellite imagery.

Synoptic Pattern

The next requirement to achieve productive interpretation is to determine the pattern and strength of today's large-scale or synoptic circulation pattern. It is necessary to identify the current synoptic-scale condition in order to determine the current range of climatological values. Generally, the synoptic pattern is clearly reflected in the large-scale cloud organization of the satellite imagery.

In the interpretation of mid-latitude satellite imagery, the familiar cloud features of jetstreams, fronts, vortices and ridges are used to establish the large-scale pattern. Features of this nature are not seen over the Arabian Sea during the Southwest Monsoon season, and only over the extreme northern portion during the Northeast Monsoon. Forecasters responsible for this area must not only become familiar with the rather unique atmospheric conditions of the northern Indian Ocean region, but must also learn to recognize and properly interpret a new array of large-scale cloud patterns.

The following examples from the text of the Handbook illustrate a few of the large-scale cloud patterns that reflect variations of the Southwest Monsoon circulation. The "Onset Vortex" that ushers in the rapid development of the fully developed Southwest Monsoon over the Arabian Sea is shown in Figure 3-4. The cloud pattern illustrating a "weak" or inactive Southwest Monsoon period is shown in Figure 3-5, and the contrasting pattern of a "strong" or active Southwest Monsoon in Figure 3-6. Other large-scale variations of the Southwest Monsoon that would be of interest and would be reflected in the overall cloud patterns are the "break" in the monsoon and "monsoon depressions." These features are addressed in the Navy Tactical Applications Guide for the Indian Ocean Volume 5 (NEPRF Technical Report TR 83-03). Recognition of these large-scale conditions should provide the clues to generate in the "mind's eye" a general overall atmospheric structure.

Local Conditions

From an understanding of the area climatology and having established the large-scale circulation pattern, we next address the scale of local deviations. On these smaller scales, there are many features which we see in imagery over the monsoon regions that have the same cause and effect relationships as similar mid-latitude features, e.g., cloud types, barrier effects, upwelling, terrain features, etc. These small-scale features can be used both in a collective manner to develop the large-scale pattern (similar to analysis of plotted station reports), and to interpret the causative atmospheric conditions useful in making short-term forecasts. The trick is to be able to deduce the causative atmospheric conditions from the features seen in the imagery.

TECHNOLOGICAL ASPECTS

The analyst must have an awareness of the technological aspects of the satellite sensors; data transmission and reception modes and the viewing angle of the satellite to maximize use of the data. In the following interpretive illustrations for example, Figure C-2 is an infrared image recorded with a special purpose enhancement curve. In this example, a rather restricted range was in use with 16 gray shades spread over a temperature range of 25°C (22°C to -3°C). This enhancement provides good descriptive patterns in the range of the Arabian Sea sea-surface temperatures (SST) and low-level cloud features, but quickly goes to black (22°C) over land and to white (-3°C) when cirrus clouds are present. Each gray shade reflects a temperature range of about 1.6°C (25°C divided by 16).

ILLUSTRATIONS OF IMAGERY INTERPRETATION DURING THE SOUTHWEST MONSOON

Figures C-1 and C-2 are simultaneous visual (VIS) and infrared (IR) images of the western Arabian Sea region on July 9, 1979 (approximately 1000 (0629Z) local sun time at the center of the image). They reflect a "weak" Southwest Monsoon period, one day prior to Figure 3-5. Three large-scale features are reflected and labeled with Roman numerals. The cloud pattern over the Arabian Sea (I) is generally suppressed with little convective activity, clearly in contrast to the pattern during active Southwest Monsoon flow as illustrated in the text (Figure 3-6). The cloud-free conditions over land (II) are typical of the regions occupied by the surface thermal lows that prevail throughout the Southwest Monsoon period. The upper-level Easterly Jet, as reflected by the cirrus pattern (III), while quite evident in the IR, would be recognized as relatively weak compared to a pattern representative of an active monsoon period. The large-scale information gained from Figures C-1 and C-2, then, is this: a "weak" Southwest Monsoon flow pattern with markedly reduced convective activity, a correspondingly weak upper-level Easterly Jet over the Arabian Sea and typical cloud-free conditions over the land areas of the thermal lows.

A number of small-scale features can also be identified in Figures C-1 and C-2. These are labeled with Arabic numerals. The features so identified can be used both to support the large-scale interpretations (i.e., they reflect conditions typically found under these large-scale patterns), and to determine the various atmospheric conditions useful as short-range forecasting guidance.

Numeral (1); Interpretation: Dust Plume. A local dust plume is seen just northwest of the northern end of the Persian Gulf. To interpret this feature from the VIS image (Figure C-1) alone requires knowledge of the unobstructed terrain features of this area (see Figure 3-10). Close inspection of the IR image transparency shows a faint gray feature reflecting the cooler temperature of the top of the dust plume, but the photographic print (Figure C-2) fails to reproduce this feature. Seasonal thermal lows are located south and east of the area of the dust plume, resulting in persistent northwesterly surface winds. This wind pattern is known locally as the "Summer Shamal" or "40-day Shamal". Frequent large and local-scale dust storms are produced by this wind pattern. Because this is near the end of the Summer Shamal season and the dust plume is a very localized feature (probably raised from a dry lake bed), the surface winds are likely to be weaker than the average during the previous 4 to 6 weeks.

Numeral (2); Interpretation: SST Pattern. The faint gray shade seen in the IR indicates a slightly cooler SST over the northern Persian Gulf. There is no support for this condition in the VIS image, and none would be expected for weak SST gradients. However, climatology supports this observation.

Numeral (3); Interpretation: Upwelling. A relatively cold feature is noted in the IR off the coast of Oman. This area appears cloud-free in the VIS (3), therefore the IR feature is interpreted as an area of colder surface water. Other cold SST features (not labeled) can be seen in the cloud-free areas to the south of feature (3) along the Oman coast. In the Northern Hemisphere where prevailing southerly (northerly) winds parallel an eastern (western) coast, oceanic upwelling may occur. The Southwest Monsoon surface flow results in a flow pattern parallel to the coasts of Oman, Yemen and Somalia. A strong SST gradient is reflected by a crescent-shaped pattern (8) off Somalia. This pattern reflects an annual SST feature and is associated with the low-level Somali Jet (see Section 3.3.1).

Numerals (4) and (5); Interpretation: Low-level Inversion. Gravity wave-induced cloud patterns are seen over the northwestern Arabian Sea, implying a low-level inversion. This interpretation is based on the following factors: gravity waves are known to propagate along density interfaces such as strong atmospheric temperature inversions, and during the Southwest Monsoon, a low-level temperature inversion is known to persist over the western Arabian Sea.

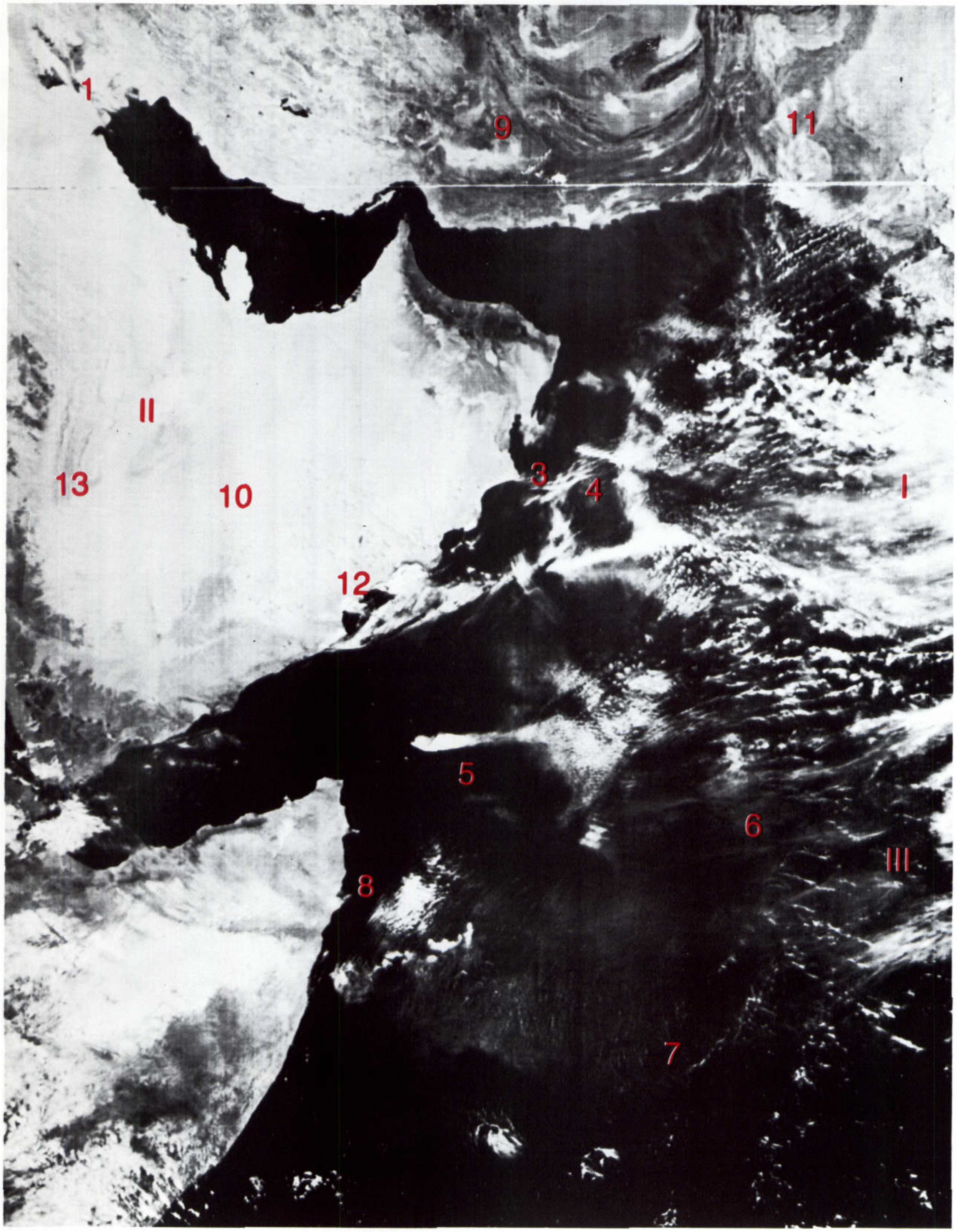

Figure C-1. DMSP visual image of the western Arabian Sea region produced from data recorded on July 9, 1979 (0629 GMT).

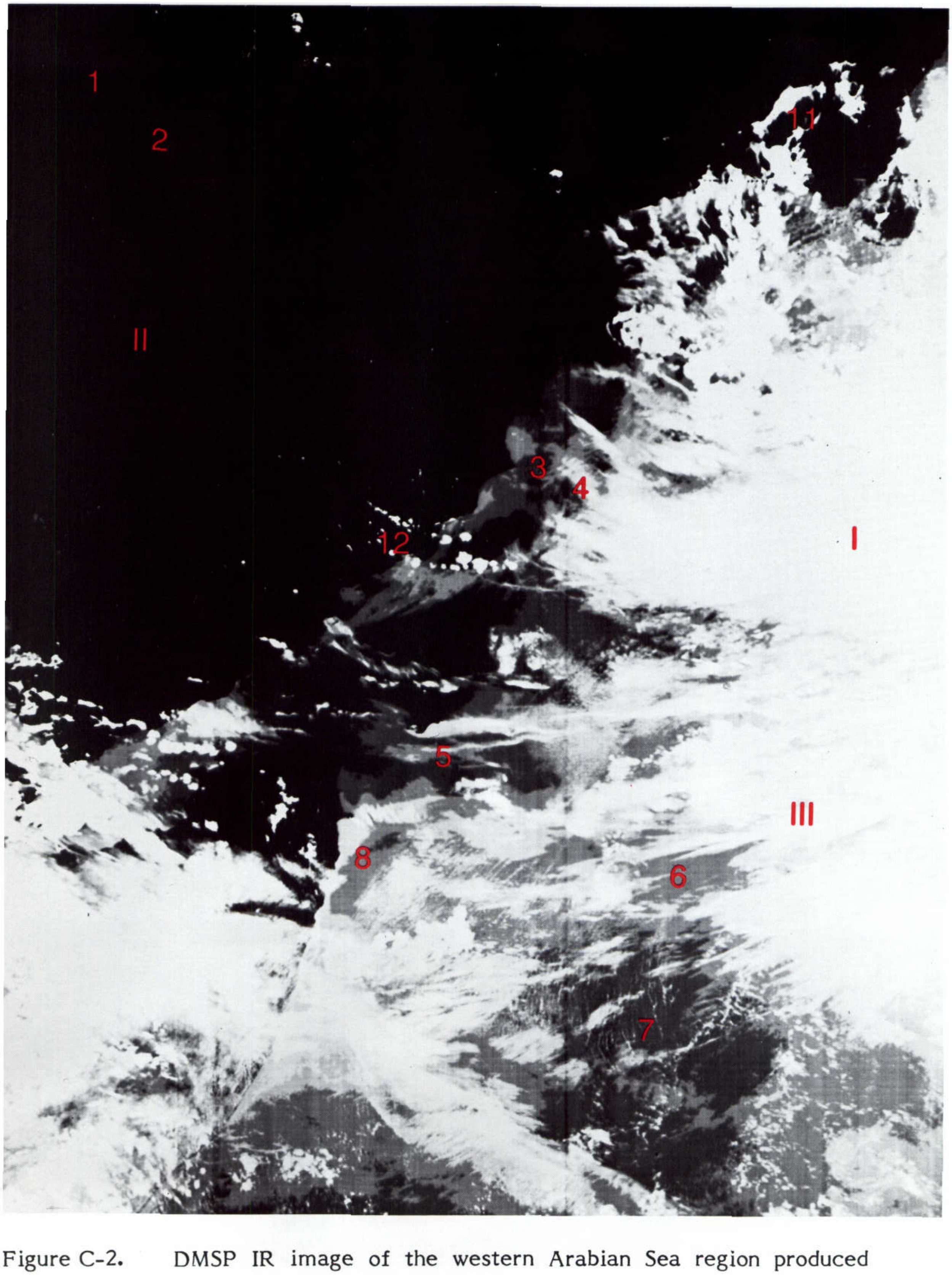

Figure C-2. DMSP IR image of the western Arabian Sea region produced from data recorded on July 9, 1979 (0629 GMT).

The Southwest Monsoon inversion-capped planetary boundary layer of the western Arabian Sea is so shallow, and vertical motion so restricted, that clouds typically do not form. During "weak" Southwest Monsoon periods, the inversion is lower than during "strong" Southwest Monsoon periods. Numeral (5) identifies a second cloud feature which indicates that a low-level inversion exists. Cloud formation is noted along the southern slopes of Socotra Island. The clouds do not stream over the island as would be expected if the southerly flow was perturbed upward over the island terrain. This implies a stable layer such as a low-level inversion.

Numeral (6); Interpretation: Upper-level Easterly Jet. Faint east-west oriented cirrus streamers are seen in the VIS image. Due to the restricted enhancement curve used in the IR image, all cloud tops colder than -3°C are seen as white. This IR enhancement is not intended for use in interpreting cirrus-level features. In this case, the interpretation of cirrus clouds in the IR image must be based on cloud shape plus position relative to the VIS image. From a climatological standpoint, the interpretation of this period as a "weak" Southwest Monsoon implies a weakened upper-level Easterly Jet condition. Comparison of Figures C-1 and 3-6 (active Southwest Monsoon) clearly indicates the difference in cirrus cloud characteristics during "weak" and "strong" Southwest Monsoon periods.

Numeral (7); Interpretation: Low-level Flow. Clockwise curving, low-level cloud lines are seen in both the VIS and IR image. This pattern persists throughout the Southwest Monsoon season. During active Southwest Monsoon periods, low-level cloud lines will be much better defined; however, convective and cirrus cloud formations may mask the low-level cloud patterns.

Numerals (9) and (10); Interpretation: Terrain Features. Various tonal shades are seen in the VIS image over the land regions. Cloud-free images over land areas of interest should be studied and retained to provide comparative images to aid in identifying small-scale cloud or dust features over land. In general, smooth surfaces are good reflectors, and appear lighter than rough surfaces. Terrain features vary widely in tonal shades, and provide excellent reference landmarks in satellite imagery. The light tonal qualities of desert conditions are seen in the vicinity of numeral (10).

Numerals (11) and (12); Interpretation: Clouds over Land. Clouds over light-toned land are seen in the vicinity of numerals (11) and (12). The clouds are not clearly evident in the VIS image, but are seen as washed-out white masses in the IR image. In the intepretation of visual imagery alone, there are two aids to identifying clouds over light-toned land; knowledge of the land feature as discussed above, and the appearance of shadows. Close inspection of the light features (clouds) near numerals (11) and (12) shows adjacent dark features (shadows) generally to the west. The image is from a late morning pass (0629 GMT). The use of shadows, however, is not fool-proof as is indicated by the thin, dark-toned bands to the west of terrain features near numeral (13). In general, cloud shadows can provide additional information on the relative height of cloud elements. The higher the cloud-top or the smaller the sun's elevation angle, the longer the shadow. Early morning or late afternoon satellite passes provide the clearest examples of cloud shadow patterns in the lower latitudes.

ILLUSTRATIONS OF IMAGERY INTERPRETATION DURING THE NORTHEAST MONSOON

Figure C-3 is a NOAA visual image of the Arabian Peninsula region on December 16, 1979 (approximately 0900 (0553Z) local sun time at the center of the image). This reflects a Northeast Monsoon (wintertime) condition. Four large-scale features are reflected and labeled with Roman numerals. The vortex and frontal band (I) of a migratory mid-latitude disturbance is located over Iran. A jetstream cirrus band (II) extends east-west over the southern Arabian Peninsula. The cirrus band is most clearly seen over the Red Sea and Gulf of Oman, but is faintly discernable over the land areas. This is most likely the Subtropical Jetstream, but the image alone does not clarify this point. Past history, large-scale analyses, or satellite passes on either side of this pass are needed to resolve the jetstream classification. A second mid-latitude disturbance (III) is seen over the extreme eastern Mediterranean Sea. A typical Northeast Monsoon (IV) cloud pattern is depicted over the western Arabian Sea. An active Near-Equatorial Trough (convergence area) is indicated by the convective activity over the equatorial oceanic region.

The large-scale interpretation of this image is that mid-latitude systems are being advected into the northern Arabian Sea region, suggesting that an equatorward extension of a mid-latitude long-wave trough exists at this time.

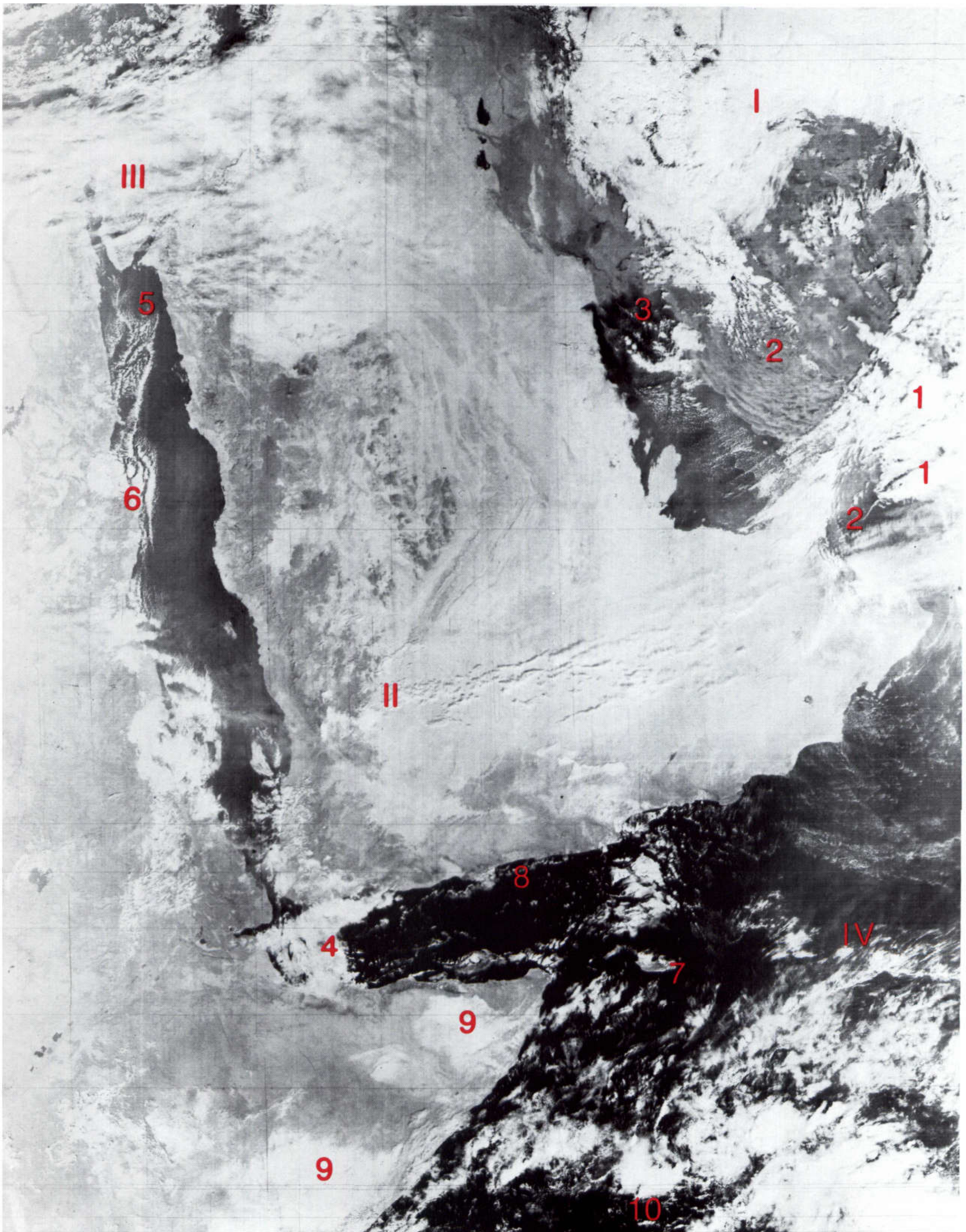

Figure C-3. NOAA visual image of the Arabian Peninsula region produced from data recorded on December 16, 1979 (0553 GMT).

Numeral (1); Interpretation: Cumulonimbus. Cumulonimbus (Cb) clouds are seen over southwestern Iran embedded in the general frontal band cloudiness. The Cb's can be identified by their point-source, fan-shaped cloud features. Additional evidence is provided by the shadows seen to the northwest of the fan-shaped features which indicate that their tops are well above the surrounding frontal cloud features. The featureless tops of these two Cb cirrus plumes indicate that they extend vertically to the tropopause. The stable layer at the tropopause restricts further vertical development, and the top of the cloud feature becomes flat and smooth in appearance.

Numeral (2); Interpretation: Wave Clouds. Wave clouds form over and downstream from terrestrial ridgelines that are aligned perpendicular to the flow at, or above the height of the ridge. In this case, the wave clouds seen over western Iran and Oman depict the lower tropospheric flow pattern associated with the migratory disturbance.

Numeral (3); Interpretation: Low-level Northwest Flow. Low-level cloud lines are seen extending southeastward over the extreme northern Persian Gulf. Cloud lines of this type typically form when cold air streams offshore over warmer water. Due to the channeling of winds by the Persian Gulf, strong, northwesterly winds locally known as the "Winter Shamal", occur frequently. The Winter Shamal sets up following the passage of a migratory low as the tight pressure gradient between the low and the following high-pressure ridge passes over the region. The cloud lines indicate the developing northwest flow over the northern Persian Gulf and the southern limit of the Shamal at this time.

Numeral (4); Interpretation: Displaced Convergence Zone Cloud Band (CZCB). The CZCB is seen south of the southern entrance to the Red Sea. This is displaced well south of its climatological norm (18-20°N) for this time of year. This implies a strong equatorward thrust of mid-latitude westerlies and correlates with the location of a migratory vortex over Iran, south of the normal storm track.

Numerals (5) and (6); Interpretation: Advection Cloudiness over the Red Sea. Cloud lines are seen over the northern Red Sea (5), implying cold air advection over the warm waters. The clouds are being advected over the western shore (6) with nearly cloud-free conditions over the eastern Red Sea. The western coastal area is lower in elevation, and the strong downslope flow from off the Arabian Peninsula tends to advect the clouds westward. This condition of greater cloudiness over the western coast prevails in all seasons for the Red Sea region. The displacement of the CZCB, and northerly flow over the entire Red Sea provide further evidence of the strong equatorward penetration of polar air.

Numerals (7) and (8); Interpretation: Northeast Monsoon Flow. Clouds are seen along the northern and eastern coasts of Socotra Island (7), implying northeasterly low level flow. Clouds are being advected onshore along the northern coast (8) of the eastern Gulf of Aden. Both of these conditions are expected during the Northeast Monsoon season when the northeast surface winds prevail over the Arabian Sea and extend into the Gulf of Aden as easterly flow. Winds are generally light in both areas.

Numeral (9); Interpretation: Stratiform Clouds over Somalia. Smooth-edged, featureless clouds are seen over Somalia. These clouds are being advected onshore along the Somali coast. This onshore flow is an extension of the northeasterly, low-level flow over the Arabian Sea. There are no shadows seen along the edges of the majority of these clouds, indicating that they are very low. They also appear to have sharply defined edges on the upslope side along terrain features. This "contouring to the terrain" is a common characteristic of stratus and fog. The suppressed vertical motion illustrated by these clouds indicates stable conditions in the lower troposphere in this area.

Numeral (10); Interpretation: Convective Clouds over the Ocean. A band of convective activity extends eastward offshore from Somalia. This is most likely an extension of the northern Near-Equatorial Trough; additional satellite coverage to the south and east is needed for clear definition. The convective activity reflects the warm low-latitude SST with cooler air above. Weak upper-level flow is indicated by the absence of cirrus streamers such as those seen in the Southwest Monsoon examples and near numeral (1).

SUMMARY

In order to optimize the use of satellite imagery, forecasters must develop and apply skills beyond routine recognition of cloud types and patterns. A systematic interpretive approach should be developed that maximizes the information contained in satellite imagery. The approach should be directed toward a synthesis of the data so that a comprehensive three-dimensional picture of the atmosphere is formulated in the mind of the forecaster.

Interpreters must adjust their reasoning and insights relative to cloud features, to the unique perspective of satellites. Imagery must be recognized as a continuous distribution of real cloud information which is far more complete than the symbolic information of conventional surface cloud observations.

Satellite interpretation should be viewed as an extension of our basic understanding of environmental processes. Without a reasonable understanding of these processes, the images become nothing more than nice pictures. On the other hand, after developing a certain level of skill in imagery interpretation, the information conveyed by the images can provide the insights necessary to develop conceptual models of the atmospheric conditions.

Typically, the process is to acquire knowledge of atmospheric processes through study and experience, then relate this knowledge to features in the imagery. The reverse thought process, i.e., deducing the atmospheric conditions from imagery features, will develop surprisingly quickly when imagery must be relied on as a primary data source. In either approach, the recognition of the "big picture", i.e., the synoptic pattern, provides the large-scale forcing to which all smaller-scale imagery features must be related.